Chapter 1
Introduction, Purpose and Need, and Overview

1.1 INTRODUCTION

The Department of Energy (DOE) directs and oversees the management of Brookhaven National Laboratory (BNL). DOE is evaluating several alternatives regarding the future of the High Flux Beam Reactor (HFBR), one of BNL's major research facilities. This research reactor is currently shutdown. DOE will decide among the following alternatives: the No Action Alternative, the Resume Operations Alternative, the Resume Operation and Enhance Facility Alternative, and the Permanent Shutdown Alternative. These alternatives are described in greater detail in Section 2.1. Several modifications will be performed to the HFBR regardless of the alternative chosen by DOE to enhance environmental and safety aspects. These modifications are described in greater detail in Section 2.3.

This Draft Environmental Impact Statement (DEIS) has been prepared by DOE to evaluate the proposed alternatives for the HFBR. The Notice of Intent (NOI) titled *Environmental Impact Statement for the High Flux Beam Reactor Transition Project at the Brookhaven National Laboratory, Upton, NY* was published by DOE in the Federal Register in November 1997 (62 FR 62572). Public scoping occurred between November 24, 1997 and January 23, 1998; a Public Scoping Report has been prepared and is available to the public (BNL 1998a). The DEIS has been produced in accordance with the *National Environmental Policy Act* of 1969 (NEPA), the Council on Environmental Quality (CEQ) regulations (40 *Code of Federal Regulations* [CFR] Parts 1500-1508), and DOE's NEPA Implementation Procedures (10 CFR Part 1021).

1. 2 PURPOSE AND NEED FOR DOE ACTION

Public Law 95-91, dated August 4, 1977, assigned responsibility to DOE for assuring a coordinated and effective administration of Federal energy policy and programs. In turn, the Office of Science is charged with maintaining long-term scientific programs oriented to large-scale, high technology research and development. One aspect of this mission is the development and application of neutron-based research. Neutrons are a unique resource essential to research in the fields of physics, chemistry, medicine, and biological sciences, as well as for the development of new materials.

From its inception in 1965 until it was shutdown in 1996, the HFBR had held the distinction of being one of the world's best sources of neutrons. Scientists from around the world came to BNL to use neutrons at the HFBR in their investigations in solid state and nuclear physics, chemistry, medicine, and biology. As many as 280 scientists visited the HFBR each year to irradiate experimental samples in the reactor or to make use of the facility's intense neutron beams. The Federal government and the scientific community require a reliable source of neutrons to continue neutron scattering research. A source with capabilities similar to the HFBR does not currently exist in the U.S.

DOE needs to make a decision on the future of the HFBR. That decision will be made from among four alternatives: No Action, Resume Operations, Resume Operation and Enhance Facility, and Permanent Shutdown. Each of these alternatives is briefly described in Section 2.1.

DOE is responding to its own need to make a decision on the HFBR's future, as well as responding to Congressional direction to prepare an Environmental Impact Statement (EIS). The Conference Report accompanying Public Law 105-62, the *Energy and Water Development Appropriations Act* of 1998, directed that an EIS be prepared on the HFBR. The Report noted the conferees' expectation that the EIS include a "comprehensive survey of any environmental hazards that the tritium leak or other contamination associated with the HFBR pose to the drinking water and health of the people in the surrounding communities, and that it will provide a detailed plan for remediation."

The leak of tritium from the HFBR spent fuel storage pool to groundwater is a major concern. Several interest groups and political figures have expressed opposition to operation of the HFBR, and in 1998 and 1999 Congress prohibited the use of funds for the restart of the HFBR.

DOE has no preferred alternative at this time. DOE will continue to involve stakeholders in this process so that stakeholder concerns can be considered and addressed. A preferred alternative will be identified in the Final HFBR EIS (FEIS).

1.2.1 CERCLA OPERABLE UNIT III SUMMARY

After completion of the initial investigation, DOE decided that the public concerns about the tritium plume should be addressed in the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) Operable Unit (OU) III Remedial Investigation/Feasibility Study (RI/FS). Data collected on groundwater flow indicate that tritium concentrations greater than the drinking water standard, given that no more tritium would be leaking from the spent fuel pool, will not cross the BNL boundary from the HFBR tritium plume due to natural decay and dilution.

In March, 1999, DOE announced a public comment period on BNL groundwater cleanup documents for OU III; the Remedial Investigation (RI) Report, Feasibility Study (FS), and the *Proposed Plan for Operable Unit III*. These documents address cleanup of groundwater contamination both on and off the BNL site.

The FS addresses remediation of tritium and other contaminants. Cleanup objectives include: meeting drinking water standards in groundwater for tritium and other contaminants; completing cleanup of groundwater in a timely manner; and preventing or minimizing further migration of contaminants.

The *Proposed Plan for Operable Unit III* identifies proposed remedies for the groundwater contamination. Since the tritium is expected to decay to levels below the drinking water standard before reaching the site boundary, monitored natural attenuation is proposed. The existing tritium pumping system that was started in 1997 would be placed in standby. This system would be restarted if monitoring of the tritium plume indicates that concentrations of tritium above the drinking water standard could migrate off site. Additional low-flow extraction wells would be installed near the HFBR and operated if tritium concentration levels adjacent to the HFBR increase significantly due to migration of tritium out of the soil beneath the HFBR. Groundwater monitoring would continue.

Proposed remedies may be modified or different removal/remedial actions may be selected based upon public comments. After consideration of public comments, DOE, U.S. Environmental Protection Agency (EPA), and New York State Department of Environmental Conservation (NYSDEC) will make a final decision on the OU III cleanup remedies. The decision will be formalized in a Record of Decision (ROD), and remediation work will be conducted under the framework of an interagency agreement among the DOE, EPA, and NYSDEC.

1.3 THE DECISION PROCESS

1.3.1 THE NEPA PROCESS

In preparing this DEIS, DOE is complying with the provisions of the *National Environmental*

Policy Act (NEPA) (42 United States Code [USC] 4321 *et seq.*). NEPA requires Federal agencies to prepare detailed statements for "major Federal actions" (proposed actions) with the potential to significantly affect the human environment (NEPA Section 102(2)(C)). Among other things, EISs are to include the environmental effects of the proposed action and alternatives to that action.

Requirements for the preparation of EISs are contained in the CEQ *Regulations For Implementing the Procedural Provisions Of NEPA* (40 CFR 1500-1508). DOE has also prepared NEPA implementing procedures (10 CFR Part 1021) to complement the CEQ regulations. DOE is required to follow the DOE and CEQ regulations when conducting environmental impact analyses under NEPA.

Prior to preparing the DEIS, the CEQ regulations require Federal agencies to solicit public input concerning the scope of the analysis to be performed. This process is called "scoping." The scoping process is summarized in Section 1.3.2. Using the information gained from scoping, DOE prepared this DEIS. Supporting documentation for DEIS analyses are available for review in the following public reading rooms: Building 477A Brookhaven Avenue at BNL, Longwood Public Library in Middle Island, Mastics-Moriches-Shirley Community Library in Shirley, Patchogue-Medford Library in Patchogue, and the DOE Forrestal Building at 1000 Independence Avenue SW in Washington, D.C. Moreover, documents that are generally available only in electronic formats (such as the *U.S. Nuclear Regulatory Commission Safety Assessment of the High Flux Beam Reactor at the Brookhaven National Laboratory*) are available for review in print format.

The public is being invited to provide input. Meetings will be held in the fall of 1999 at Berkner Hall at BNL to provide the public an opportunity to comment on the content of this DEIS. Comments may also be submitted to DOE in writing (Dr. Nand Narain, U.S. Department of Energy, Brookhaven Group, P.O. Box 5000, Upton NY, 11973-5000), by e-mail (hfbrcomments@bnl.gov), via facsimile (516-344-6097), or by telephone (888-560-9363). The dates of the public comment period will be announced in EPA's Notice of Availability for the HFBR DEIS.

In 1997, DOE issued its *Action Plan for Improved Management of Brookhaven National Laboratory*, which summarized DOE's planned process for deciding the future of the HFBR. The Action Plan states that the Secretary of Energy will decide the future of the HFBR and directs an appropriate environmental review process. That review process includes this DEIS on the HFBR. DOE is scheduled to select a preferred alternative for the future of the HFBR in 1999. The preferred alternative will take into account several factors, including the analysis of environmental impacts contained in this DEIS, public input from the local Long Island community, input from the HFBR scientific-user community and the DOE Basic Energy Sciences Advisory Committee, and the value of the scientific information produced using the HFBR.

Public comments regarding the content of this DEIS will be used to make necessary revisions. After any revisions are made, a FEIS will be made available to the public. A notice will be published in the *Federal Register* announcing the availability of the FEIS. No sooner than 30 days after the FEIS Notice of Availability, the Secretary of Energy will make a decision regarding the future of the HFBR. That decision will be presented in a ROD, which also will be published in the *Federal Register*.

1.3.2 PUBLIC INVOLVEMENT

On November 24, 1997, DOE published a Notice of Intent (NOI) in the *Federal Register* to prepare an EIS pursuant to NEPA for the HFBR at BNL (62 FR 62572). Publication of the NOI marked the beginning of the EIS scoping process.

Three scoping meetings were held to receive public input about the scope of the EIS and to identify environmental issues. All three meetings were held in the general vicinity of BNL. The first meeting was held on December 10, 1997, at the Mastic Beach Property Owners Association in Mastic Beach. The second meeting was held on January 10, 1998, at the Longwood Senior High School in Middle Island. The third meeting was held on January 15, 1998, at the North Shore Public Library in Wading River. The public was urged to provide comments to DOE verbally or in writing at each of the scoping meetings. DOE also invited comments by mail, e-mail, facsimile, or by calling a dedicated telephone number where comments were recorded. DOE requested that all comments be submitted by the end of the scoping period, which closed on January 23, 1998.

DOE received nearly 600 comments during this scoping process. All comments were reviewed to identify issues for assessment in the EIS. The comments were grouped and either deemed out of scope or placed within 13 general subject areas:

Alternatives and Analysis of Alternatives
- Land Use and Visual Resource Impacts
- Infrastructure
- Air Quality and Noise
- Surface and Groundwater Impacts
- Geology, Soils, and Seismicity
- Ecology
- Cultural Impacts
- Socioeconomic Impacts
- Environmental Justice Impacts
- Transportation Impacts
- Public and Occupational Health and Safety Impacts
- Waste Management
- Cumulative Impacts

Some commenters requested that the EIS be as thorough as possible and that DOE take the necessary time to perform the requisite analyses. Commenters were especially concerned about protecting groundwater and surface water, and about the potential for HFBR activities to contribute further to groundwater contamination. Some commenters were concerned with potential health risks from long-term exposure to radioactive and hazardous materials. Concerns were also expressed regarding the potential for reactor accidents and offsite consequences to public health and safety from those hypothesized accidents.

Some comments received were outside of the scope of this EIS. For example, DOE shares the view that the lack of a national repository for nuclear waste is a concern, however national policy is beyond the scope of the HFBR EIS. Other concerns have been addressed in other documents. For example, concerns about the nuclear fuel cycle are more properly addressed in the DOE *Programmatic Spent Nuclear Fuel Management* EIS, which analyzed the management of DOE spent fuel until the year 2035.

A report summarizing the public scoping process and relevant issues identified for analysis was prepared by DOE. The *Public Scoping Report* (BNL 1998a) is available for review, along with all public comment letters, e-mail, facsimiles, telephone comments and scoping meeting transcripts, at the following public reading rooms: Building 477A Brookhaven Avenue at BNL, Longwood Public Library in Middle Island, Mastics-Moriches-Shirley Community Library in Shirley, Patchogue-Medford Library in Patchogue, and the DOE Forrestal Building at 1000 Independence Avenue SW in Washington, D.C.

1.3.3 SIGNIFICANT ISSUES FOR ANALYSIS

The environmental issues raised during the scoping process relate to human health and safety, water resources, socioeconomics, and waste management.

Public concerns regarding human health and safety were primarily related to the potential adverse effects of long-term exposure to low-level concentrations of tritium in drinking water supplies. Other concerns related to the epidemiological studies and data that address potential adverse health effects in nearby offsite populations. The socioeconomic issues raised relate to job creation or loss from restart or shutdown of HFBR. Waste management issues concerned the generation, storage, and disposal of wastes at BNL. Potential adverse effects from offsite transportation of waste for disposal also was raised as an issue needing analysis in the EIS.

1.4 POLICY AND PUBLIC LAW CONSIDERATIONS

Section 512 of the Conference Report accompanying Public Law 105-62, the *Energy and Water Development Appropriations Act* of 1998, directed that an EIS be prepared on the HFBR (H.R. 1997). The Report noted the conferees' expectation that the EIS will be "a comprehensive survey of any environmental hazards that the tritium leak or other contamination associated with the HFBR pose to the drinking water and the health of the people in the surrounding communities, and that it will provide a detailed plan for remediation." Long-term remediation plans are being prepared under the ongoing CERCLA OU III program and will be discussed with the local community. Consistent with Congress' direction, the HFBR EIS summarizes the remediation plan and program, and assesses the HFBR's potential for further contribution to groundwater contamination.

The Conference Report also directed DOE to drain the HFBR spent fuel pool, meet the requirements outlined in the Suffolk County Sanitary Code, Article 12, complete seismic upgrades, and repair and seal the floor drains. Several additional repairs and modifications will be made to bring the HFBR into compliance with applicable Federal, State, and local laws and requirements. The Conference Report prohibited the use of funds for restarting the HFBR in fiscal 1998, and the *Energy and Water Development Appropriations Act* of 1999 (Public Law 105-245) prohibits the use of 1999 funds for restarting the HFBR.

DOE has also directed BNL to construct and install a double-walled stainless steel liner in the spent fuel pool to ensure that the spent fuel pool would not become a source of groundwater contamination in the future. The spent fuel pool would be used in the future whether or not the reactor is restarted. For example, during deactivation the spent fuel pool would be used to hold various highly radioactive reactor components which must be dismantled or cut apart prior to shipment offsite. As part of the CERCLA process, DOE committed to control the source of groundwater contamination, which was the spent fuel pool. Since there will be a need to use the spent fuel pool under any of the alternatives, and to conform with Suffolk County Sanitary Code, Article 12 requirements, the liner will need to be installed prior to any use of the spent fuel pool.

Since the spent fuel pool has been drained, the HFBR-related source for the tritium plume has been removed. There is essentially no relationship between the HFBR alternatives being considered and the CERCLA OU III program discussed in Section 1.2.1. (For further discussion of OUs and remediation, see Section 3.5.2.4.1) Moreover, although the Conference Report accompanying the *Energy and Water Development Appropriations Act* of 1998 (Public Law 105-62) prohibited the use of funds for restarting the HFBR, the Conference Report directed DOE to implement remedial actions that will be needed regardless of the final decision on the future of the HFBR. Site cleanup and tritium remediation will occur regardless of the alternative chosen.

1.5 RELATIONSHIP TO OTHER DOE ACTIONS

1.5.1 INTERAGENCY COOPERATION

DOE has coordinated the preparation of this EIS with other appropriate Federal, State, and local agencies. In May 1992, the Interagency Agreement (IAG) between DOE, U.S. Environmental Protection Agency (EPA), and NYSDEC became effective to ensure compliance with CERCLA. The IAG requires that environmental impacts associated with past activities at BNL are thoroughly and adequately investigated so that appropriate response actions can be formulated, assessed, and implemented. As noted above, DOE's remediation activities have been performed in consultation and coordination of the EPA, NYSDEC, and Suffolk County Department of Health Services (SCDHS). The final decision on the future of the HFBR will be made with input from these agencies and will be determined only after all environmental issues are fully considered.

The issue of emergency preparedness for the HFBR is important to the community. BNL has and continues to coordinate emergency preparedness activities with New York State, Suffolk County, and the towns surrounding the BNL site. BNL has an established emergency plan for the site that includes the HFBR. The emergency plan is based on the hazard assessment of the BNL facilities. Both the hazard assessment and the emergency plan are available in the public reading rooms identified in Section 1.3.2. In light of the community concerns regarding offsite emergency preparedness, BNL, New York State, Suffolk County, and the towns surrounding BNL share emergency plans and work to coordinate emergency planning, and to conduct training and exercises. BNL is a member of Suffolk County's Local Emergency Planning Committee and participates in mutual aid agreements with Suffolk County Fire Rescue and Emergency Services, Suffolk County Police Department, Stony Brook University Hospital and the Town of Brookhaven.

1.5.2 RELATED DOCUMENTS AND NEPA REVIEWS

1.5.2.1 Brookhaven National Laboratory Final Environmental Impact Statement

The *Brookhaven National Laboratory Final Environmental Impact Statement* (ERDA-1540) (BNL EIS), issued in July 1977, evaluated the environmental impacts of alternatives associated with operations and functions at BNL. Environmental impacts were evaluated for routine facility operations as well as for full and partial termination of operations for various onsite facilities. Analyses of operating the HFBR at 40 MW were conducted since the HFBR was initially designed to operate at that power level. The BNL EIS also analyzed and supported upgrading the HFBR to operate at up to 60 MW. Along with the overall evaluation of environmental impacts resulting from various site operations, environmental impacts resulting from the operation of the HFBR were specifically addressed. HFBR impacts evaluated in the BNL EIS include those resulting from gaseous effluents, liquid effluents, and solid wastes. Radiological health impacts and impacts from potential accidents were also evaluated.

1.5.2.2 U.S. Nuclear Regulatory Commission Safety Assessment of the High Flux Beam Reactor at the Brookhaven National Laboratory

In June 1997, the House Committee on Appropriations authorized DOE to provide up to $225,000 directly to the U.S. Nuclear Regulatory Commission (NRC) for identification and assessment of significant HFBR safety issues, compliance with DOE safety requirements, and potential issues related to regulation of BNL by entities other than DOE. The NRC staff evaluation of the HFBR (NRC 1999) focused on HFBR reactor safety programs. NRC safety evaluation guidance and inspection procedures, and applicable industry and other Federal standards provided guidance for this safety assessment. This NRC staff safety assessment included observations of ongoing activities to the extent possible; review on an audit basis of procedures, records, and programs; and discussions with personnel on specific topics. Although the reactor has not operated since December 1996, the HFBR safety programs were assessed over the range of power levels at which the reactor previously operated (the HFBR has previously operated up to power levels of 60 MW). The NRC assessment covered approximately the last three years.

The NRC assessment "identified no safety-significant issues, although several apparent instances of noncompliance with DOE and BNL requirements were noted." The report concludes that "the safety programs at the HFBR were found to provide adequate protection of health and safety of the public, the workers, and the environment." The NRC report also concludes that "actions taken to characterize and control the groundwater tritium plume were conservative, and this tritium plume does not present a radiological hazard to public health or safety. Monitoring and control of effluents at the HFBR were acceptable. Releases were well below the applicable limits and followed ALARA [as low as reasonably achievable] practices."

1.5.2.3 Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement

The *Programmatic Spent Nuclear Fuel* (SNF) *Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (DOE/EIS-0203-F), issued in April 1995, is contained in two volumes. The SNF Programmatic Environmental Impact Statement (PEIS), volume 1, considers (DOE-wide) alternative approaches to safely, efficiently, and responsibly manage existing and projected quantities of spent nuclear fuel until the year 2035. The SNF EIS does not analyze the ultimate disposition (final step in which material is disposed) of SNF. Decisions regarding the disposition of DOE's SNF will follow appropriate review under the NEPA and be subject to licensing by the NRC. Volume 2 of the document addresses alternative approaches for the management of DOE's environmental restoration, waste management, and SNF activities over the next 10 years at the DOE site that is now known as the Idaho National Engineering and Environmental Laboratory.

Of the reasonable alternatives evaluated in the SNF EIS, only the No Action and Decentralization Alternatives would have required SNF from the HFBR to be stored at or near the site of generation. Each of the remaining alternatives (including DOE's Preferred Alternative known as Regionalization) involves the offsite shipment of SNF from the HFBR to one or more sites evaluated in the SNF EIS. On May 30, 1995, DOE issued a ROD (60 FR 28680, June 1, 1995) implementing the Preferred Alternative of Regionalization. As a result of this decision, all SNF that may result from potential future HFBR operations will be shipped to the Savannah River Site (SRS) for storage prior to ultimate disposition. Appendix I to the SNF PEIS contains detailed analyses of the transportation impacts associated with the transportation of SNF from BNL to other sites for disposition. The ROD for this HFBR EIS, when issued, will be consistent with the ROD for the SNF EIS.

1.5.2.4 Final Waste Management Programmatic Environmental Impact Statement

The *Final Waste Management* (WM) *Programmatic Environmental Impact Statement* (DOE/EIS-0200-F), issued in May 1997, evaluates the environmental impacts of managing five types of radioactive and hazardous wastes generated by past and future nuclear defense and research activities at a variety of DOE sites within the United States. The five waste types are low-level mixed waste (LLMW), low-level waste (LLW), transuranic waste (TRU), high-level waste, and hazardous waste. The WM PEIS provides information to assist DOE with decisions on the management of, and facilities for, the treatment, storage, and/or disposal of radioactive, hazardous, and mixed wastes.

Wastes would be generated, to differing degrees, as a result of each of the alternatives considered in the HFBR EIS. Generally these wastes include hazardous nonradiological wastes (generally referred to as hazardous waste), nonhazardous nonradiological waste (called industrial waste in the HFBR EIS), LLMW (called mixed waste in the HFBR EIS), and LLW. In its ROD for hazardous waste (63 FR 41810, August 5, 1998), DOE decided to continue to use offsite facilities for the treatment of major portions of the non-wastewater hazardous waste generated at DOE sites, including BNL. Analysis of nonhazardous nonradiological (industrial) waste was beyond the scope of the WM PEIS and not analyzed for any of the DOE sites considered in the document, including BNL. The remaining wastes evaluated in the WM PEIS are LLMW and LLW. Although specific roles for BNL in the Waste Management Program will not be determined until the RODs for each waste type are issued, the following preferred waste management alternatives are being considered for BNL.

Low-Level Mixed Waste: DOE prefers to ship BNL's LLMW, including mixed waste from the HFBR, offsite for treatment consistent with BNL's proposed site treatment plan. DOE prefers to ship BNL's LLMW to one of two or three regional sites for treatment and disposal.

Low-Level Waste: DOE prefers to treat BNL's LLW onsite, including LLW from the HFBR, prior to shipping LLW to one of two or three regional disposal sites. Treatment of LLW primarily involves processes to package the LLW for safe transport and disposal.

Both the WM PEIS and the HFBR EIS consider waste management strategies. The WM PEIS considers alternatives that include local, regional, and/or consolidated waste management facilities. The HFBR EIS addresses alternatives that will result in the generation of LLMW and LLW. The waste management strategies for the HFBR are consistent with the WM PEIS, however the RODs will require coordination.

1.5.2.5 Spallation Neutron Source Environmental Impact Statement

The *Construction and Operation of the Spallation Neutron Source Facility Final Environmental Impact Statement* (SNS) (DOE/EIS-0247), was issued in April 1999; the ROD was issued in June 1999 (64 FR 35140). The SNS facility will consist of a proton accelerator system, a spallation target, and appropriate experimental areas, laboratories, offices, and support facilities to allow ongoing and expanded programs of neutron research. The alternative sites under consideration were four DOE-owned laboratories: Argonne National Laboratory, Argonne, Illinois; Los Alamos National Laboratory, Los Alamos, New Mexico; Oak Ridge National Laboratory, Oak Ridge, Tennessee; and BNL, Upton, New York.

The SNS facility will produce short pulses of neutrons for use in materials research. The research will reveal information on the structure, properties, and behavior of various test materials. Like a reactor-based source of neutrons, such as the HFBR prior to its shutdown, the SNS would produce neutrons. However, the SNS will use pulsed accelerator technology to produce high energy neutrons for specific research applications whereas research that relies solely on integrated neutron fluxes requires the use of a reactor-based neutron source. DOE considers the SNS to be a complementary addition to neutron research, along with reactor-based neutron sources. DOE has designated Oak Ridge National Laboratory in Oak Ridge, Tennessee as the site for the SNS.

1.6 BNL OVERVIEW

The following sections present a brief history of BNL and describe the major research missions that have been undertaken since its inception, as well as the current missions of the laboratory. Also, a description of the major research facilities is provided.

1.6.1 HISTORY OF BNL

BNL was established in 1947 as a national research center for the peaceful uses of atomic energy. BNL is located on a former Army base known as Camp Upton, which was declared surplus at the end of the Second World War. BNL is situated near the geographic center of Suffolk County, Long Island, about 100 kilometers (km) (60 miles [mi]) from New York City (see Figure 1.6–1 and Figure 1.6–2). BNL occupies approximately 2,150 hectares (ha) (5,300 acres), with most facilities located near the center of the site (BNL 1995a).

When BNL opened in January 1947, it was one of three federally funded facilities designed to conduct nuclear research that was beyond the resource capabilities of individual universities. Much of this research was performed using nuclear reactors and particle accelerators. In the early 1950s the Brookhaven Graphite Research Reactor (BGRR), the Cosmotron (a proton synchrotron), and a hot lab to handle nuclear engineering and chemistry were built. The additional infrastructure and personnel required to operate these facilities contributed to the further development of the BNL site and growth in the laboratory's work force. By 1958 a medical research reactor and two low-power accelerators were in operation (BNL 1995a).

A second generation of reactors and accelerators was built during the 1960s. The Alternating Gradient Synchrotron (AGS), a 33 GeV proton accelerator, was completed in 1960. The AGS has been used by high energy and particle physicists to probe the basic structure of matter by examining the behavior of subatomic particles as they collide with targets at nearly the speed of light. The Brookhaven Linac Isotope Producer (BLIP) was attached to the end of the linear accelerator leading into the AGS, allowing the production of useful radionuclides without interfering with AGS work. The HFBR, a research reactor providing thermal neutrons, was completed in 1965. The HFBR has been used in a variety of research programs, including solid state physics, nuclear physics, materials technology, structural biology, medicine, and chemistry. The Tandem Van de Graaff electrostatic accelerator (for years, the world's largest electrostatic accelerator) was completed in 1970 (BNL 1995a).

This period of BNL's rapid growth came to a halt at the end of the 1960s when a large nuclear engineering program to develop a liquid metal fuel reactor was terminated. As a result, BNL's workforce decreased and by 1971 over 890 ha (2,200 acres) of land were declared surplus by the Department of the Interior and the land was transferred to New York State for use as parkland. The land is currently undeveloped (BNL 1995a).

BNL gained a new mission at the end of the 1970s, with the development of the National Synchrotron Light Source (NSLS), which was designed to use intense focussed light spanning the electro-magnetic spectrum as a research tool to study matter. The facility was commissioned in 1982 and expanded in 1983 to accommodate increased demand. By 1997, the NSLS facility was supporting more than 2,500 researchers from over 450 university, industrial, and Government institutions (BNL 1995a).

In 1978, work began on the Vacuum Ultraviolet and x-ray storage rings for the NSLS. In the 1980s, the construction of a transfer tunnel between the Tandem Van de Graaff accelerators, the AGS, and the AGS Booster facility brought heavy ion development to the AGS (BNL 1995a).

The most recent major addition to BNL is the Relativistic Heavy Ion Collider (RHIC), which was approved for construction in 1991 and was completed in June, 1999. This facility is BNL's largest and most powerful accelerator — the first of its kind to create a quark-gluon plasma, a form of hot dense matter that is thought to have existed for only a few moments immediately after the universe was formed (BNL 1995a).

Figure 1.6-1. Location of Brookhaven National Laboratory on Long Island.

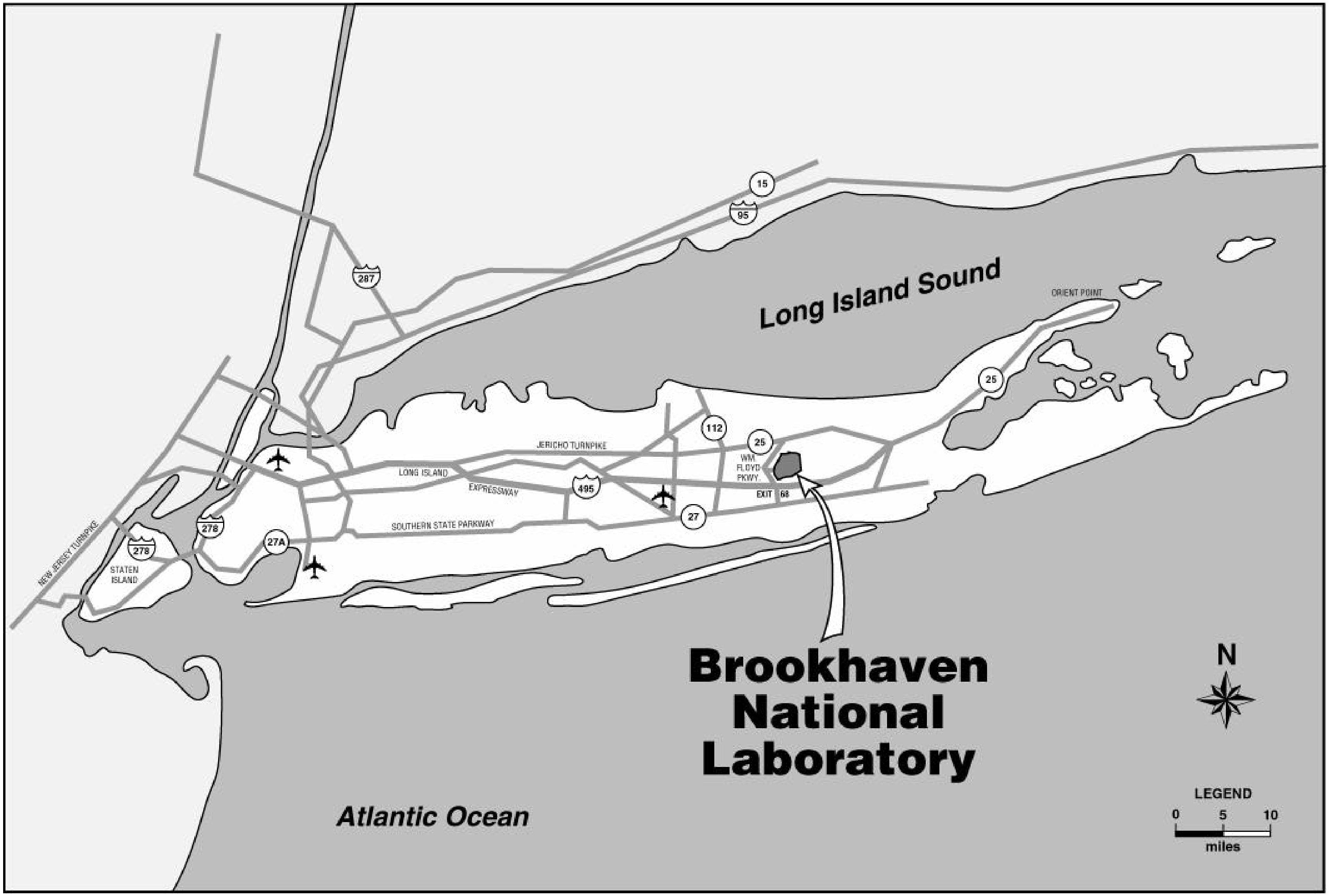
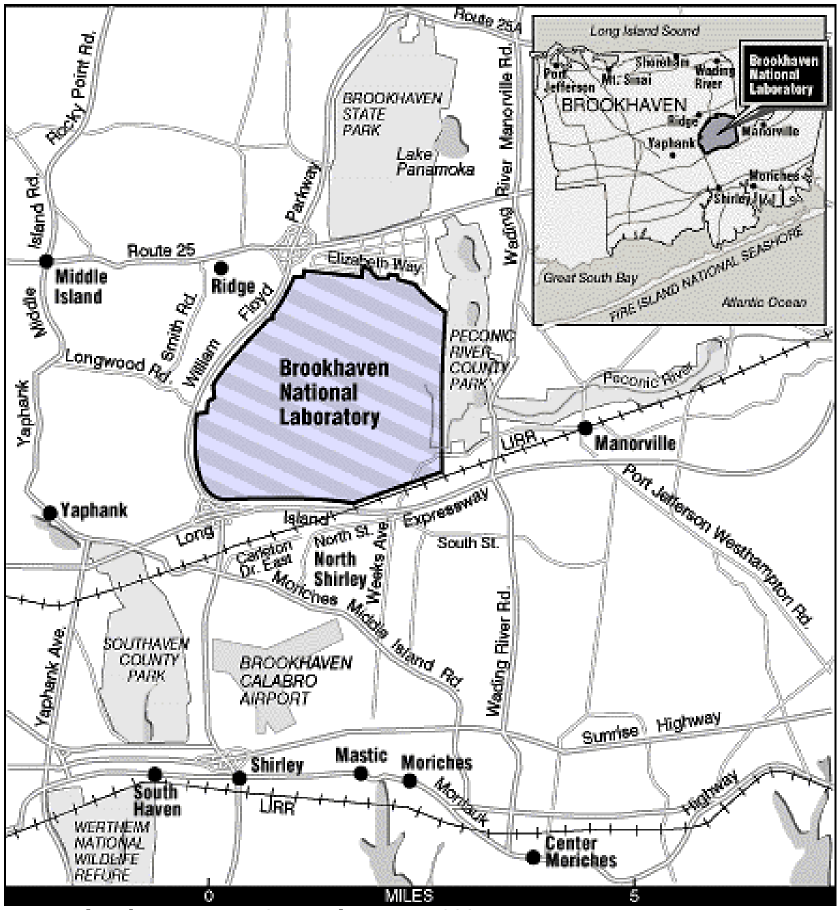


Figure 1.6–2. Location of BNL



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Note: This figure is oriented so that the top of the figure is north.

1.6.2 Current Missions and Major Research Facilities

1.6.2.1 Current Missions

BNL has four core missions: designing, building, and operating research facilities; scientific research; technology development; and knowledge transfer.

Under the first mission, BNL is dedicated to designing, building, and operating complex, leading-edge, user-oriented research facilities in a safe and environmentally sound manner. These are the facilities that allow BNL to conduct its other missions in accordance with all applicable environmental, safety and health laws and regulations. The facilities, such as particle accelerators and colliders, nuclear reactors, and synchrotron storage rings, are used for fundamental scientific studies in basic and applied research.

BNL's scientific research mission encompasses a wide range of disciplines in the physical and biological sciences. The major research areas include:

- High energy particle and nuclear physics
- Advanced accelerator concepts
- Materials and chemical science
- Environmental science, medical science, and biotechnology
- Molecular biology
- Advanced scientific computing and systems analysis

The technology development mission focuses on developing advanced technologies to address national needs, support and strengthen DOE's ability to carry out its missions, support other Federal, State, and local agencies, and benefit industry. Major technology development activities include:

- Advanced accelerator designs
- Biomedical applications of nuclear technology
- Neutron and synchrotron x-ray scattering
- Development and production of radionuclides and radiopharmaceuticals

BNL's fourth core mission encompasses knowledge transfer and includes:

- Fellowship programs for training scientists and engineers
- Public education
- Technology transfer and information technology
- Training programs for technologists

An important component of the fourth core mission is BNL's effort to help transfer newly developed technologies to the private sector. This is accomplished through several conduits including BNL's Technology Transfer Office, which provides technical assistance to industry, maintains an exchange program, and establishes research partnerships with industry.

1.6.2.2 Major Research Facilities

BNL has four large research facilities (see Figure 1.6–3) including RHIC, which was completed in 1999. As discussed earlier, the NSLS has over 2,500 users and is used for both basic scientific research and industrial applications. The AGS, the nation's only high energy polarized proton source for research in the fields of particle and nuclear physics and radiobiology, supports the work of over 900 researchers. Prior to its shutdown, the HFBR employed approximately 120 scientists and other personnel, and was used by over 280 visiting scientists for condensed matter physics, biology, chemistry, and medical and industrial applications. It is anticipated that RHIC will be used by over 800 scientists when in full operation. BNL operates several biomedical research centers including the Brookhaven Center for Imaging and Neuroscience, the linear isotope production facility, and a medical radiation facility. BNL also maintains a nuclear data center and a radiation chemistry research facility (BNL 1995a).

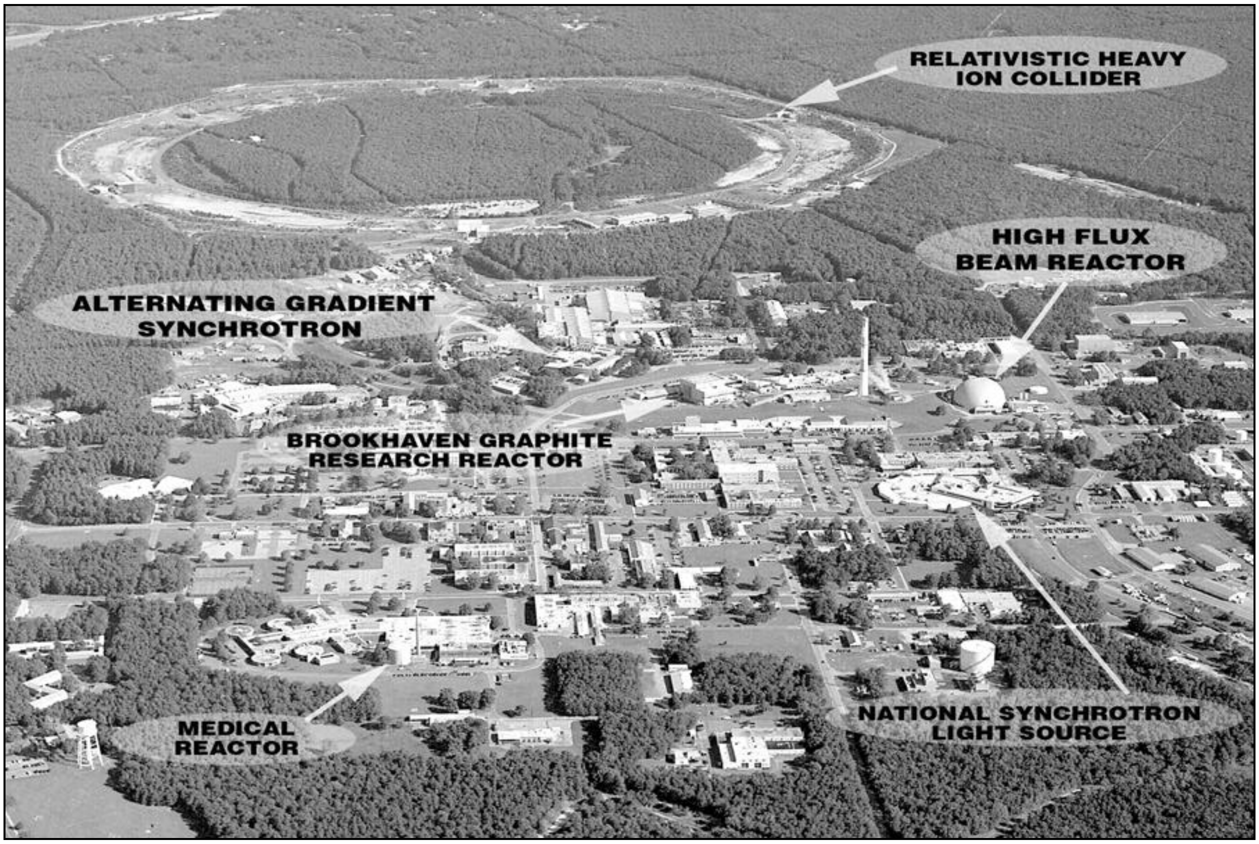
1.7 HFBR OVERVIEW

1.7.1 HISTORY OF THE HFBR

The HFBR is one of the world's premier steady-state neutron sources. An international center for neutron scattering investigations in solid state and nuclear physics, chemistry, medicine, and biology, researchers and scientists come from all over the world to use the HFBR. In 1996 alone, 280 people from the United States and 12 foreign countries came to BNL to use the HFBR — and other scientists sent an additional 180 samples to be studied. The HFBR has been used since 1965 as a scientific facility dedicated to neutron scattering research and other research programs in physics, materials technology, and biomedical sciences. Neutron scattering techniques are used to study the structure and properties of materials. The HFBR has provided about two-thirds of DOE's reactor-based experimental neutron scattering capability (BNL 1992).

The HFBR uses heavy water (deuterium oxide, or D_2O, which is water whose hydrogen atom has an extra neutron in its nucleus) for cooling and a highly enriched uranium (HEU) (U^{235}) core to produce beams of thermal neutrons that are guided to experimental areas by nine horizontal aluminum alloy tubes called "beam tubes." In addition, there are seven vertical tubes for irradiating research samples in the reactor. The entire reactor and its control room are enclosed within a confinement dome, as can be seen to the right of center in Figure 1.6–2. The reactor has been used exclusively for research and does not produce electric power. The reactor has not been used for any weapons-related research and such use is not contemplated.

Figure 1.6–3. BNL Facilities.



At the end of 1997 the HFBR staff consisted of about 120 scientists, engineers, technicians, and administrative personnel. Approximately 300 researchers from U.S. industries and universities, Japan, and several countries in Europe comprise the rest of the HFBR user community (BNL 1998b).

For some research areas, the HFBR is considered the best facility in the United States. For example, the facility's Small Angle Neutron Scattering (SANS) capability is regarded as a particularly useful technique by structural biologists, who represent a rapidly growing user community for neutron scattering. The HFBR SANS offers unique capabilities for the study of biological samples and is the best resource in the United States for this type of work. In addition, the HFBR's Single Crystal Neutron Diffraction equipment complements x-ray techniques in determining the structure of complex organic molecules because of its ability to locate hydrogen atoms. The HFBR facility has also been used for radioisotope production, neutron activation analysis, and material irradiation (BNL 1992; BNL 1998c).

1.7.1.1 Unique Capabilities of the HFBR

The HFBR produces beams of neutrons used to study the structure and properties of matter. To understand how this is done and why it is worthwhile requires a review of some of the properties of the neutron. All atoms are composed of a heavy core or nucleus, surrounded by a cloud of much lighter electrons. The nucleus is composed of positively charged subatomic particles called protons and neutrons. Neutrons are subatomic particles about as heavy as the proton, but are not electrically charged. Neutrons all by themselves are exceedingly rare because it is hard to pry them loose from the atomic nucleus. The HFBR was specially designed to unlock neutrons from the atomic nucleus and to direct them into narrow guided beams. The neutron beams can then be focussed on materials to help unravel the structure and properties of those materials.

Uranium is the only naturally occurring element that occasionally releases neutrons from its nucleus. Only once in every few million billion years will a uranium nucleus spontaneously break roughly in two, liberating two or three neutrons in the process. Even though a few ounces of uranium contains billions of atoms, it is far too weak a source to produce beams of neutrons for research purposes. However, if one of those liberated neutrons is absorbed by another uranium nucleus, it may cause that uranium nucleus to break up, also. In a specially designed and shielded container, which is called a nuclear reactor, this process — the chain reaction — can be repeated many times in a controlled manner. In this way, a beam of neutrons can be generated that is strong enough for research purposes (for example, to reveal the structure and properties of the materials under study).

The principles of the operation of the HFBR are the same as those which govern nuclear power reactors, which are built to produce large amounts of heat to turn steam into electricity. However, the HFBR is much smaller and simpler in design than power reactors. Research reactors also use less fuel and produce far less radioactive waste. In terms of size and power, it would take about 100 HFBR-sized reactors to produce as much heat as a typical power reactor.

Neutrons are important for research because they allow scientists to determine the position and motion of atoms in a piece of material. Scientists must somehow “see” inside the material with a suitable magnifying glass. No ordinary microscope allows us to see individual atoms. In principle, ordinary light permits observation of objects separated by about one thousandth of an inch, which is more than one thousand times the separation of atoms.

Another alternative for studying matter might be x-rays. X-rays have wavelengths much shorter than those of visible light, and are widely used to “see” atomic positions by studying how atoms scatter a beam of x-rays. However, not all atoms are equally “visible” to x-rays. For example, dental x-rays are not stopped by light atoms in the soft tissue of the face nearly so well as by the heavy mercury atoms of dental amalgam in tooth fillings. This makes it difficult to study living cells using x-rays.

Neutrons, because they interact with the nucleus of the atom rather than the electron cloud, allow us to see light and heavy atoms about equally well. This is important because most useful modern materials contain light as well as heavy atoms, and many others (for example, plastics and living cells) are composed almost entirely of light atoms. Scientists can use neutrons in ways that are impossible with x-rays. For example, a virus consists of its genetic code (DNA) surrounded by a protective covering of protein. By dissolving viruses in mixtures of ordinary and heavy water, beams of neutrons can “see” (or scatter from) only the DNA or only the protein outer layer, depending on the heavy water concentration. This method can be used with living cells, allowing scientists to study the cell surface or the cell contents, and creating the unique possibilities for the study of biological structures with neutrons.

Neutrons can also penetrate more deeply into most materials before they are absorbed or scattered. For example, a beam of neutrons can easily penetrate a quarter-inch thick plate of aluminum. By contrast, a beam of x-rays is almost completely absorbed within 1/100th of an inch. This makes neutrons the tool of choice for finding flaws in steel rails or jet turbine blades.

The HFBR offers scientists two ways to perform their experiments — neutron irradiation and neutron scattering — as presented in Figure 1.7–1. The HFBR is designed with the flexibility to utilize different methodologies so that neutrons can either be used entirely within the reactor core or extracted through “beam tubes” for experimental purposes.

1.7.1.2 Research Achievements

The HFBR has a history of cutting-edge research in a variety of fields:

- Boron compounds developed in HFBR research are being studied for the efficacy in treating as-yet-incurable brain cancer. Glioblastoma multiforme, for example, affects over 7000 Americans each year. Because these new compounds collect primarily in tumor tissue rather than healthy tissue, when the malignant mass is irradiated the boron absorbs neutrons and releases powerful, but very short-range radiation that kills the tumor cells (BNL 1998e).

- Another medical radioisotope developed at the HFBR is tin-117 (Sn^{117}), a tin radioisotope. It is being tested as a pain reliever for bone cancer patients (approximately 320,000 cases occur each year in the United States alone), and works without the adverse side effects caused by opiates. Moreover, when the isotope is attached to a pharmaceutical known as “DTPA” (diethylenetriamine pentaacetic acid) and injected into the patient, it tends to lodge within bone rather than soft tissue. Because the electrons emitted from the decay of Sn^{117} have a very short range in tissue, the tumors on the bone receive up to 50 times more dose than radiation-sensitive bone marrow. As a result, bone marrow production of white blood cells or platelets is not suppressed, enabling the body to continue to fight infection (BNL 1995b).

- Small-angle neutron scattering — possible only because of the development of high flux neutron sources — has made important contributions to understanding the structure of DNA, the biological blueprint in a living cell. These studies are crucial to the understanding of cellular functions, how the cell makes selected proteins, DNA repair, and reproduction (BNL 1998f).

- Neutron studies at the HFBR have demonstrated the structure of the inactive form of plasminogen, a blood clot dissolving enzyme normally found in the bloodstream. This knowledge led to greater understanding of a new anti-clotting drug, Tissue Plasminogen Activator, increasing the drug’s efficacy and contributing to the treatment of heart attack and stroke victims when blood clots are involved — saving an estimated 17,000 lives per year in the U.S. alone (BNL 1998g).

- Studies of micellar structures have led to an understanding of how they cluster and separate. This knowledge has resulted in formulations that are used to emulsify paint and food so that the products will maintain a smooth texture, create solutions that more completely extract oil from oil wells, and optimize delivery systems for water-insoluble drugs and medications (BNL 1998h).

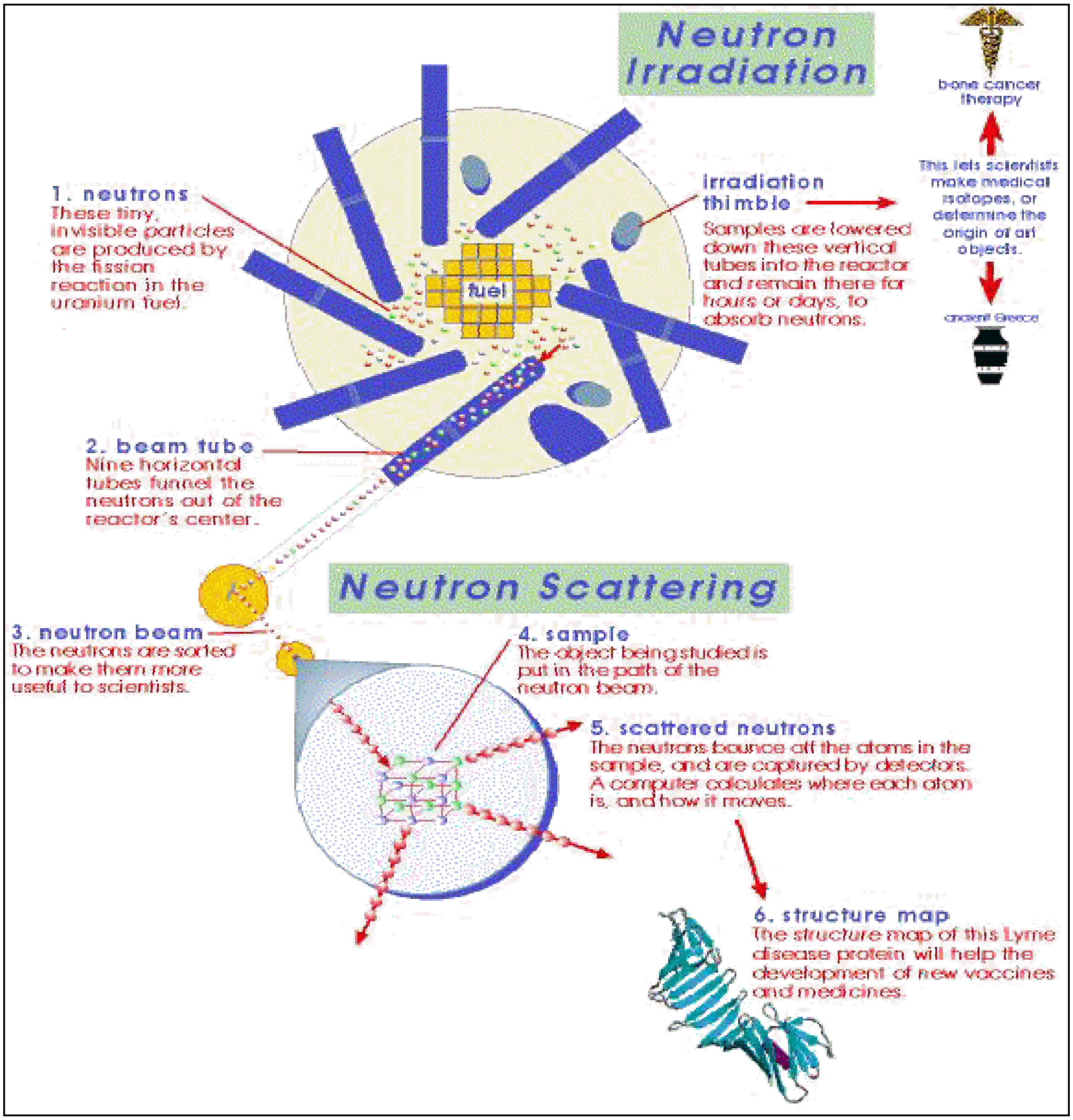
- Researchers at the HFBR assisted art historians by using neutron activation analysis to examine quarried stone. The data collected allowed art historians to identify the geographic origins of statues currently in museum collections. This knowledge also allows historians to identify possible copies as well as identify restorations (Scientist 1995).

- The technetium-99 metastable isotope (Tc^{99m}), discovered through HFBR research, is used to diagnose traumatic injury to internal organs. More than 10 million test kits are used each year in the U.S. alone to assist in locating hemorrhages in human patients (BNL 1998i). Moreover, Tc^{99m} is the most widely used radioisotope in the diagnosis of diseased organs because the type of radiation it emits allows the practitioner to image internal body organs without causing radiation damage. In a recently developed application, Tc^{99m} is being used to locate the infected lymph nodes in breast cancer patients, enabling doctors to locate nodes precisely before beginning surgery (BNL 1998j).

- Techniques developed by scientists at the HFBR are used in obesity studies, enabling new body composition methodologies (StL-RHC 1997).

- Protein studies at HFBR have allowed the creation of more precisely targeted pharmaceuticals (BNL 1998k).

Figure 1.7–1. The HFBR Offers Scientists Two Ways to Perform Their Experiments — Neutron Irradiation and Neutron Scattering.



Source: BNL 1998d.

• The HFBR has been involved with research on Lyme disease (BNL 1997a).

• By grafting block copolymers onto the surface of small solid particles called "colloids", researchers found that the ability of the particles to attract oil was improved. This research may have applications that will assist cleaning up environmental oil spills (BNL 1998l).

1.7.1.3 Planned and Future Research

Examples of planned and future research include the following projects:

• Continuing research on the structure of membrane proteins that protect cells from flu-like viruses may someday reduce risks of contracting some illnesses (BNL 1998l).

• Studies of polymer mixing may one day lead to better, cheaper ways to recycle mixed plastic waste like polystyrene coffee cups and polyethylene milk bottles (BNL 1998l).

• Greater understanding of materials known as copolymers (which promote adhesion between dissimilar plastics) may lead to safer truck tires (which often fail by delamination) and to pot-hole resistant asphalt (which fails in freeze-thaw cycles because of poor bonding between the actual asphalt and the rock aggregate) (BNL 1998l).

• The further study of batteries, in an attempt to produce cheaper, environmentally compatible electrode materials, has possible applications in next-generation battery-powered cars (BNL 1998m).

• Understanding the mechanism for ferro-electricity and other structural transformations may have future applications to solid state electronics (BNL 1998m).

1.7.2 ROLE OF THE HFBR IN PROVIDING NEUTRONS FOR RESEARCH

A research reactor is one that is designed and operated for a purpose other than to produce power. There are hundreds of such reactors in the world; some were built to study the operation of reactors themselves and to train reactor operators. Others (isotope reactors) were designed to use the neutrons produced to make new radioactive isotopes — atoms with more neutrons in the core than can occur stably in nature. These artificial isotopes find uses in medicine to diagnose and treat injuries and diseases. Most of these reactors are not well-suited to the generation of beams of neutrons.

The HFBR was the first reactor in the United States designed from the outset to provide intense beams of neutrons for research purposes. It is the only reactor of this design in the U.S. Although the HFBR was designed more than 30 years ago, the principles of that design have not been improved upon in the United States. After the HFBR was built, a reactor of similar design was built in France, and is operated for the use of a group of European nations. It is difficult for U.S. researchers to gain access to that facility, as the research program is oversubscribed. (When a research program is “oversubscribed”, there are more researchers wanting to use the facility than there are research stations.) Moreover, the U.S. is not part of the consortium that funds the French reactor, which lowers the priority of any projects that might be proposed by U.S. researchers.

The most powerful research reactor presently operating in the U.S. is the High Flux Isotope Reactor in Oak Ridge, TN. Because it was designed primarily to make isotopes, it has fewer facilities for using neutron beams. There is a reactor that is very useful for doing neutron scattering experiments at the National Institute for Science and Technology in Gaithersburg, MD, but it operates at lower power than the HFBR. The neutron beam research programs at both the Oak Ridge and Gaithersburg reactors are oversubscribed.

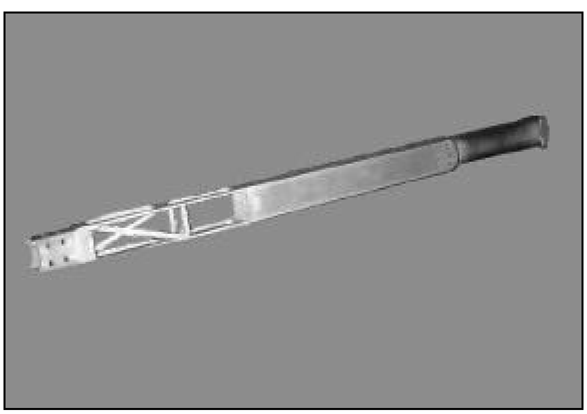
In addition to the unique design of the HFBR reactor itself, many of the instruments built by the research scientists at the HFBR are one-of-a-kind. In principle, given sufficient time and money, these instruments could be reproduced at other reactor facilities, along with the scientific expertise necessary to use them, but they would necessarily displace other existing instruments and programs.

For many years, scientific committees have noted the shortage of neutron beam facilities in this country, especially relative to western Europe, and have recommended both upgrading existing U.S. facilities and building new facilities. About five years ago, DOE abandoned plans to build a new research reactor, the Advanced Neutron Source, because of its cost (approximately three billion dollars). It is feasible to upgrade the HFBR to double its current research capability for an expenditure far less than the construction of a new research reactor. DOE has proposed a new neutron beam facility (the Spallation Neutron Source) to be built at Oak Ridge, TN, with construction to start late in the year 2000. If the funding and construction go as planned, this facility — which would generate neutrons using a proton accelerator rather than a research reactor — would help alleviate the shortage of neutrons for beam research in the U.S. Scientists believe that the need for reactor-based sources like the HFBR would continue.

1.7.3 THE HFBR AND PHYSICAL PLANT

The HFBR would use highly enriched U^{235} (93%) fuel and a heavy water moderator to sustain a controlled nuclear chain reaction. The core would consist of 28 fuel elements; each element would contain 18 curved fuel plates. In each plate uranium oxide powder would be mixed with aluminum powder to form a core — called a cermet core — which is then encased in an aluminum cladding. The cladding acts as a barrier or containment for the radioactive isotopes formed as fission by-products of the controlled nuclear chain reaction. A sample fuel element is represented in Figure 1.7–2. The fuel element shown is approximately 1.45 meters (m) long (4.75 feet [ft]) long, approximately 7.45 centimeters (cm) (2.9 inches [in]) wide, and approximately 6.6 cm (2.6 in) deep (BNL 1992, BNL 1996a).

Figure 1.7–2. A Fuel Element from the HFBR Core.



Typically, the fuel elements are placed in a roughly cylindrical arrangement inside a spherical aluminum reactor vessel with a diameter of about 2 m (6.6 ft). The existing core is approximately 58 cm (22.8 in) high and 48 cm (18.9 in) in diameter. The core would have an active volume of about 97 liters (l) (25.6 gallons [gal]) and would contain a maximum of 9.8 kilograms (kg) (21.6 pounds [lb]) of U^{235}. The existing core is about the size of a small refrigerator, approximately 330 l (87.2 gal). The D_2O would be pumped downward through the spaces between the fuel element plates carrying away the heat that would develop in the core. The D_2O would be circulated through a pair of heat exchangers where the heat would be transferred to a light water (H_2O) secondary loop which would dissipate the heat into the air through a set of cooling towers. In a standard power reactor, which is typically 100 times more powerful than the HFBR, it is this heat which is used to produce steam for turbines and production of electricity. However, the HFBR would be a research reactor, geared to the production of neutrons. The HFBR's operating temperature would be close to 60º Celsius (C) (140º Fahrenheit [F]), considerably cooler than a commercial power reactor's operating temperature of 540 ºC (1000 ºF) (BNL 1992).

Outside the reactor vessel is a water-cooled thermal shield of steel and lead 23 cm (more than 9 in) thick. This shield protects the surrounding outer shield from excessive heating. The outer shield, known as the biological shield, protects the reactor operators and experimenters from the radiation produced in the reactor. The biological shield, which has a minimum thickness of 2.4 m (almost 8 ft), is a mixture of heavy concrete and steel (BNL 1992). The configuration of the thermal and biological shields provides a secondary containment which functions to keep the reactor core covered with cooling water in the event of a potential leak from the reactor vessel.

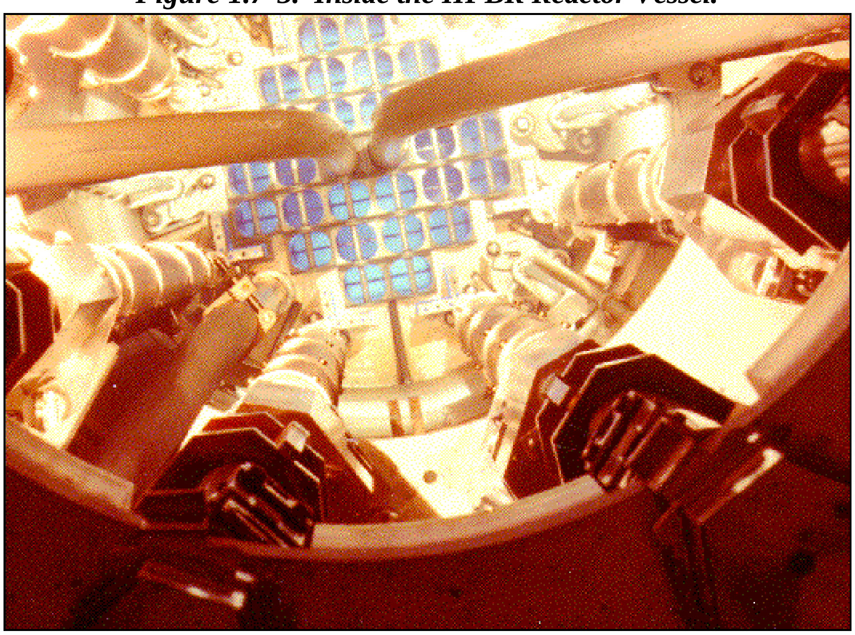
In contrast to a commercial power reactor which is designed to minimize the escape of neutrons from the core, the HFBR has been specifically designed to maximize the number of neutrons available to external beams. This is accomplished through the choice of coolant and core configuration. D_2O, rather than light water, was selected as the coolant and moderator for this reactor because it is less likely to absorb neutrons. The core volume of D_2O would not be sufficient to slow down all of the neutrons within the fuel region. Many of the neutrons would thus escape from the fuel region and would then slow down (or "thermalize") in the large volume of coolant which surrounds the core. Some of these thermalized neutrons are reflected back into the core to sustain the nuclear chain reaction, while the rest would be available as candidates for extraction through beam tubes to experimental stations (BNL 1992).

Sixteen control rods containing dysprosium and europium oxides would act as neutron "poisons" to absorb the thermal neutrons and control the rate at which the nuclear chain reaction would take place. Rods would be arranged just outside the core in two groups, a main bank which can be raised above the core, and an auxiliary bank which can be lowered below the core. Only the main control rods are required to safely shutdown the reactor. Shutdown of the nuclear chain reaction is accomplished by inserting the control rods around the core to prevent the return of thermal neutrons. During normal operation, the desired high neutron flux is maintained constant at the midplane of the core by positioning control rods above and below the midplane of the core as fuel depletion progresses. Figure 1.7–3, taken from the top of the reactor vessel, shows four control rod drives. The tops of the 28 fuel elements can be seen also (BNL 1992, BNL 1998c).

During 30 MW operation, the reactor would operate for 24 hours per day for a cycle of 30 days. At 60 MW, the reactor would operate for 24 hours a day for a cycle of about 25 days. The refueling shutdown would normally last for 5 to 7 days, depending on the amount of maintenance and surveillance testing. The seven fuel elements that would have had the greatest burnup would be replaced by fresh fuel (14 elements would be replaced at 60 MW operation), and the other elements would be rearranged in the core to use the fuel in each element as efficiently as possible.

The reactor, the auxiliary equipment, and the experimental facilities would be contained in a welded steel hemisphere approximately 54 m (about 175 ft) in diameter that forms the reactor building. The air pressure inside the building would be normally kept slightly lower than atmospheric (outside air) pressure to ensure that any air leakage would be inward rather than

Figure 1.7–3. Inside the HFBR Reactor Vessel.

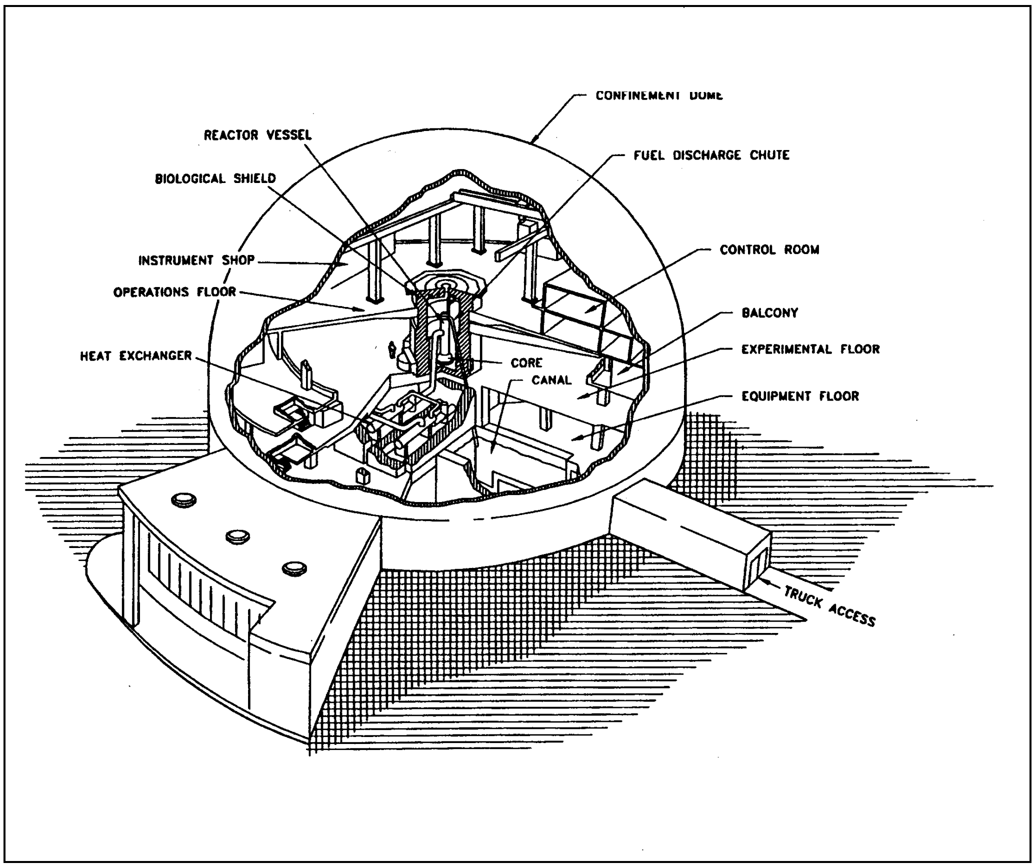


outward. Access to the existing building is provided by a system of air locks. In addition to the thermal shield around the reactor and the outer biological shield consisting of 2.4 m (7.9 ft) of concrete and steel, this existing outer building would provide an additional layer of confinement against any accidental escape of radioactive material into the environment. During reactor operation, all ventilated air leaving the building would be processed through special filters before being discharged (BNL 1992).

There are three floors within the existing reactor building, shown in a cutaway view in Figure 1.7–4. The lowest is the equipment floor which houses heat exchangers, cooling water pumps, air and water purification systems, air conditioning systems, and the equipment for supplying the building with electrical power, steam, hot water and compressed air (BNL 1992).

The middle floor houses the existing experimental floor. The centerline of the spherical part of the reactor vessel is approximately 1.2 m (4 ft) above floor level. Nine horizontal beam ports would supply neutrons to shielded beam lines which convey neutrons to the various experiments. In addition to the experimental apparatus, this floor contains existing supplementary experimental equipment, computing facilities, laboratories, and machine shops needed to support the experiments. An existing balcony level above the experimental floor houses offices and employee facilities. A 20-ton polar crane and air locks for moving heavy equipment in and out of the building also exist (BNL 1992).

Figure 1.7–4. A Cutaway View of the HFBR.



The third floor houses the existing reactor control room, along with the pumps and heat exchangers for the experimental facilities cooling system, coolant storage facilities, offices, and workrooms (BNL 1992).

The HFBR was originally designed to operate at a power level of 40 MW. An equipment upgrade, completed in 1982, allowed operation at 60 MW and greatly enhanced the reactor's scientific capability. In 1988, the National Academy of Science/National Research Council issued a report on safety issues at DOE test and research reactors. The report noted that potential dose rates from a hypothetical HFBR loss of reactor coolant accident at 60 MW and exposure to operators during such an event were not adequately addressed. The HFBR was shut down to address this issue. In 1991, after several analyses with different experts, a conservatively determined power level of 35.4 MW was set below which fuel damage leading to exposure of operators would not occur. To provide an additional margin of safety, DOE authorized operation of the HFBR at 30 MW. Subsequent analyses indicated that the HFBR could be safely operated at 60 MW (BNL 1997b, DOE 1998). Scientific users have recommended operating the reactor at 60 MW, and have requested that DOE upgrade and modernize the scientific instrumentation and other features such as the beam tubes (62 FR 62572).

1.8 TRITIUM AND REMEDIATION

Tritium is a naturally occurring isotope of hydrogen. Most tritium, however, is artificially produced in nuclear reactors. It has the same chemical properties as hydrogen but it is radioactive. Because it is an isotope of hydrogen, it is easily incorporated into water in the atmosphere and may return to the earth's surface as rain or snow.

In consumer applications, tritium is used in luminous instrument and watch dials, in "night" scopes used by hunters, and in aviation landing lights. Approximately 20 Curies (Ci) of tritium is found in unpowered exit signs, like those on most commercial aircraft. Tritium is also used in medical and biological research for tracer studies.

Tritium emits low-energy beta particles that can be stopped by skin, water, glass, aluminum, and plastics. However, tritium can pose a health hazard if inhaled or swallowed. Tritium has a radioactive half-life of approximately 12.3 years. This means that in 12.3 years, half of the radioactive nuclei in any amount of tritium will change into stable, nonradioactive helium-3 (He^3). Tritium is a pure beta particle emitter, and the beta energy in tritium is very weak. If tritium gas is inhaled, only a small amount of the gas stays in the body because tritium is rapidly removed through exhalation. However, tritium atoms readily exchange with normal hydrogen in water and the tritiated water (HTO) may be retained for longer periods in the body.

HTO interacts with the human body in the same manner as regular water. Whether in vapor or liquid form, HTO water can enter the body through inhalation, ingestion or absorption through the skin. Once inside the body, HTO is distributed throughout the body as regular water would be. HTO remains in the body a relatively short time and is eliminated in the same manner as regular water. Within 10 days, about half of the tritium that has entered the body is naturally eliminated.

The production of tritium is a byproduct of the operation of a reactor, and release of radioactive emissions would be an unavoidable adverse consequence of operating the HFBR. Radioactivity, primarily tritium, would be released in air emissions from the HFBR stack and trace amounts from the cooling towers. These emissions would have a minor adverse impact on air quality. Small amounts of tritium also would be contained in liquid effluents piped to the Sewage Treatment Plant (STP) and subsequently discharged (under State Pollutant Discharge Elimination System [SPDES] permit) into the Peconic River. Trace amounts of tritium may also be contained in cooling water discharged to Recharge Basin HO. These discharges are discussed in Section 3.5. The cumulative effects of these releases are discussed in Section 4.14.

1.8.1 AIRBORNE RELEASES

Under normal operations, very small amounts of tritium would be released from the HFBR as follows. As discussed in Section 1.7.3, the HFBR would use heavy water to cool the reactor fuel and control neutrons produced and used in the fission process. Heavy water flowing through and around the fuel would be exposed to a dense neutron field, and tritium would be produced in the heavy water when the deuterium nuclei absorb neutrons. The amount of tritium in the primary cooling water would be dependent upon the reactor power level, the number of days per year that the reactor would be at power, and the amount of time that elapsed since the last time the reactor had been shutdown or the coolant changed. This, in turn, would determine the amount of tritium that could be released as an airborne or liquid effluent. The primary means by which tritium would be transferred from the reactor cooling system into the atmosphere would be through the depressurization of the reactor vessel and through evaporative losses that would occur during maintenance and refueling operations. HTO would be released from the reactor system into the building air exhaust system. From the exhaust system, it would be routed to the facility's 106 m (350 ft) stack. Radiological impacts would not necessarily be greater for higher power operating alternatives than for the low power operating alternatives. To keep tritium concentrations and releases as low as possible, the heavy water reactor coolant would be replaced periodically, with more frequent replacements occurring at higher operating power levels.

1.8.2 WATER RELEASES

In addition to the airborne releases discussed above, tritium would also be released from the HFBR as a liquid. HTO vapor would accumulate inside the confinement building as a result of fuel handling or other operations and maintenance activities that would require the opening of primary coolant systems. Fugitive emissions from facility components would also contribute to routine releases and contamination of nonradioactive water flowing through the sanitary system. Historically, liquid releases of tritium occurred when the building air handling system condensed HTO vapor in the air and also when air came in contact with any system being discharged to the sanitary system. Some of this condensate entered the sanitary waste system and was transported to the STP. To reduce the tritium levels in the sanitary waste system, the discharge from the air conditioners to the sanitary system on the Equipment Level was stopped in 1995. The Operations Level condensate discharge was stopped in early 1996. These process changes during 1995 and 1996 constitute a significant change that resulted in permanent reductions of sanitary tritium discharges. Condensate that would be collected from areas with elevated background tritium concentrations would be used either as makeup water for the spent fuel pool or disposed of as liquid radwaste. For the last 15 years, the amount of tritium discharged to the Peconic River has decreased from a high of almost 12 Ci in 1984 to less than two in 1996, a decrease of 83% (Ports 1998a).

Under normal operations, wastewater containing trace amounts of tritium from the HFBR would be discharged to the STP, which discharges to the Peconic River via a SPDES permitted outfall. The discharge from the HFBR to the Peconic River via the STP currently is estimated to be 0.15 MLD (40,000 GPD) (Ports 1998b). Even though the HFBR is not operational, tritium is present in the sanitary system under current conditions. Maintenance activities and fugitive emissions from facility components result in low levels of airborne tritium vapor within the HFBR confinement. The vapor can come in contact with water being discharged to the sanitary system resulting in some tritium contamination of the liquid effluent (BNL 1996b).

BNL monitors radiological parameters at the outfall to the Peconic River from the STP in accordance with DOE Order 5400.5, *Radiation*

Protection of the Public and the Environment. The outfall is analyzed daily for tritium. Under the *Safe Drinking Water Act* (SDWA), the tritium concentration in drinking water must not exceed 20,000 picocuries of tritium per liter (pCi/ℓ). The NYSDEC has adopted the same standard. In 1997, the most recent year for which the *Site Environmental Report* has been prepared, the annual average tritium concentration in the STP Peconic River outfall was 1,366 pCi/ℓ or 7 percent of the drinking water standard (BNL 1999). This continues a trend of annual tritium concentrations below 20,000 pCi/ℓ that has existed since 1987 (BNL 1996b). It should be noted that although drinking water standards are used for comparison purposes, the Peconic River is not used as a source of potable water.

When the HFBR was operating, secondary cooling water from the cooling towers was discharged to Recharge Basin HO under a SPDES permit. As is the case with the discharge to the Peconic River, the primary chemical of concern in this discharge was tritium. Non-radiological chemicals were added for cooling water chemistry control, and were monitored under the SPDES permit at Recharge Basin HO. As will be discussed in Section 3.11.2.2, the use of these chemicals did not pose much risk to humans or the environment. Since the facility is not operational, there is currently no flow to the cooling towers.

The incremental contribution of tritium releases to groundwater from operations would be small, if any. No release from the spent fuel pool or as a result of normal maintenance would be anticipated. Cooling water discharges to recharge basins would also be expected to contain only trace amounts of tritium.

Consequently, because the source of the discharges that contaminated the groundwater under the HFBR has been eliminated, and the lack of other actions that would contribute to cumulative tritium impacts on groundwater resources in the vicinity of the HFBR, the thresholds for significance of groundwater impacts would not be exceeded.

1.8.3 PAST PROBLEMS

In December 1996, during a routine shutdown of the reactor for refueling and maintenance, sampling of monitoring wells indicated that elevated levels of tritiated water was contaminating the groundwater in excess of drinking water standards at locations south and down-gradient of the reactor. DOE, in cooperation with the EPA, NYSDEC, and SCDHS, immediately initiated activities to identify and eliminate the source of the tritiated water. These activities, collectively called the Tritium Remediation Project (TRP), continued as part of DOE's commitment to remediate the contaminated groundwater (62 FR 62572).

1.8.3.1 Source Evaluation

In 1997, the HFBR facility and its associated processes, facilities and exterior grounds were evaluated to identify potential sources of tritium to the environment. Four potential sources associated with the HFBR were identified (BNL 1997c). These include:

The HFBR Spent Fuel Pool: Samples taken near the reactor initially revealed approximately 40,000 pCi/ℓ of tritium in the groundwater. (Other samples, taken later at other locations, gave higher readings.) The EPA drinking water standard allows no more than 20,000 pCi/ℓ for drinking water. The HFBR spent fuel pool was identified as the source of tritium, and is estimated to have been leaking about 23 ℓ – 34 ℓ (6 gal – 9 gal) per day (Burke 1997).

HFBR Building Equipment Level Leaks and Spills: There have been several leaks and spills of tritium contaminated water, including a primary coolant pump-seal leak which occurred in July 1995. The 1995 primary coolant leak was of sufficient volume and high enough tritium concentrations that, if it had been left unattended for a long period of time, it could have potentially become a source of groundwater contamination. The spill (a total of approximately 570 ℓ [150 gal]) was subsequently vacuumed up. However, this source would have appeared as a spike in the tritium levels; it did not. The quantity and duration was insufficient to have created or maintained the present tritium plume. Also, tritiated waste materials may have leaked to the ground beneath the reactor through seams, cracks, floor penetrations, and piping and may have contributed to the plume of tritiated groundwater (BNL 1997d).

The HFBR Secondary Cooling Water System. The Tritium Remediation Project study eliminated the Secondary Cooling Water System based on the nominal tritium concentration (1,100 pCi/l) in the secondary cooling water. However, the presence of tritium in the secondary water warranted further investigation. During normal system operation, the pressure on the heavy water side of the heat exchangers is maintained higher than the pressure on the secondary side. A leak in the heat exchanger tubes could therefore lead to contamination of the secondary water system. Leak tests of the system have shown that the leakage rate from the primary heat exchanger is approximately 0.5 ml/day (0.017 fl oz/d, or 1/10th of a measured teaspoon) and from the shutdown heat exchanger is approximately 0.008 ml/day (0.0003 fl oz/d) (BNL 1998o).

HFBR Sanitary System: Portions of the BNL sanitary system external to the HFBR building were eliminated as a potential source because the nominal discharge tritium concentration was insufficient to result in the observed plume. However, historically discrete sources of tritiated water, primarily from the air conditioning system, were introduced to the sanitary system within the HFBR confinement building. Therefore, leakage from below-grade portions of the system in areas receiving higher concentrations of tritiated water may have contributed to the plume. A leak test conducted in November 1997 showed a loss rate of approximately 15 lpd to 26 lpd (4 GPD to 7 GPD), indicating that the below-grade sanitary piping is in reasonably good condition and confirming that it could not be a major contributor to the existing tritium contamination (BNL 1998n). Although it was found not to contribute to the existing plume, it should be noted that the sewage system external to the HFBR building consists of approximately 50 km (30 mi) of piping, most dating back to World War II, and that there is an ongoing major project to repair or replace this piping in conformance with Suffolk County Sanitary Code, Articles 7 and 12.

Analyses indicated that the HFBR spent fuel pool was the source of the tritium plume, and is supported by the following facts:

- results of the groundwater sampling indicate high tritium concentrations downgradient of the HFBR
- low concentrations occur immediately upgradient of the HFBR
- contamination was very high near the top of the water table in the immediate vicinity of the reactor
- no unusual levels of tritium are detected outside of the groundwater flow path from the reactor
- tritium plume concentration data are consistent with a long-term continuous source
- two separate leak tests confirm that the spent fuel pool leak rate was about 23 l – 34 l (6 gal – 9 gal) per day (Burke 1997)

The full extent of the tritium plume was tracked through the collection of groundwater samples taken from 121 temporary groundwater monitoring wells. Approximately 1,900 samples were collected initially from 45 Geoprobe™ (single-sample well probes) and 76 vertical profile boreholes. Of those early samples, about 1,500 were used for tritium analysis and the remainder were archived for possible future analysis. The results of those initial analyses were used to update the known extent of the plume and to guide the placement of new wells and the collection of additional samples. In addition to the Geoprobe™ and vertical profile boreholes, 27 permanent monitoring wells and piezometers were installed to provide long-term plume and water level monitoring. Two horizontal wells were installed beneath the HFBR building itself to track the source of the tritium (Burke 1997).

As samples were collected, it became evident that the highest concentrations of tritium were those close to the HFBR and within 3 m (10 ft) of the water table. As the plume moves downgradient from the HFBR, the levels of tritium decrease and the plume actually moves below the water table. Near Brookhaven Avenue, approximately 300 m (1,000 ft) away from the HFBR, the highest tritium concentrations were found approximately 11 m – 17 m (35 ft – 55 ft) below the water table.

The combined sampling and monitoring results have defined the tritium plume. The plume is located entirely within the boundaries of BNL, with the portion exceeding the SDWA tritium standard of 20,000 pCi/l extending approximately 800 m (2,600 ft) south of the HFBR. The highest concentration of tritium was detected immediately south of the HFBR building (1,590,000 pCi/l) and concentrations decrease to 6,440 pCi/l approximately 1,100 m (3,600 ft) south. Currently the leading edge of the 20,000 pCi/l isoconcentration line of the plume is approximately 1,500 m (4,800 ft) north of the BNL southern boundary. This plume occurs at a depth of 12 m to 15 m (40 ft to 150 ft) below the land surface and its maximum width is about 76 m (250 ft) wide. Tritium concentrations at the leading edge of the plume are less than 1,000 pCi/l. At the average groundwater velocity of 0.25 m/d (0.8 ft/d), it will take groundwater at the leading edge 16 years to reach the boundary. In that time, natural radioactive decay alone will reduce the tritium concentration to less than one-half of its current level. Therefore, even without remediation the HFBR tritium plume will never cross the BNL boundary in excess of drinking water standards (BNL 1998n).

1.8.3.2 Tritium Remediation Project

In response to the spent fuel pool leak, DOE and BNL established the TRP in the spring of 1997 to implement an interim accelerated response to ensure the protection of public health and the environment. The interim response included well drilling, tritium sampling, engineering evaluations, and groundwater modeling discussed above. The BNL site has been divided into six OUs for cleaning up the results of previous activities, not just the tritium plume. Each operable unit represents a discrete action that comprises an incremental step toward comprehensively addressing site problems. After completion of the initial investigation, the TRP has been merged into the CERCLA *Operable Unit III Remedial Investigation/ Feasibility Study* (BNL 1998p). The final remedial action will be determined through the OU III RI/FS and will be based on additional data collected.

BNL began operating an interim pump-and-recharge system to intercept the tritium plume in May 1997. The system is designed to ensure that tritium concentrations above the EPA drinking water standard of 20,000 pCi/l will not leave the BNL site. The groundwater extraction system provides a level of redundancy because current understanding of the tritium plume and groundwater flow indicates that tritium greater than the drinking water standard will never cross the BNL boundary from the HFBR tritium plume due to natural decay and dilution (BNL 1998n).

Three extraction wells were installed approximately 1,100 m (3,500 ft) south of the HFBR near Princeton Avenue in an area where the maximum tritium concentration is 6,440 pCi/l. Groundwater is pumped from a depth of about 45 m (150 ft) below land surface and piped 1,000 m (3,300 ft) northward to an existing recharge basin within the BNL site and discharged under NYSDEC permit. Prior to discharge into the recharge basin, the collected groundwater passes through activated carbon to remove chemical contamination that is also present due to other past BNL activities not associated with the HFBR. The maximum tritium concentration entering the infiltration basin historically was 1,800 pCi/l, and it is currently below detection limits (400 pCi/l) (Hauptman 1998). Samples are analyzed on a regular basis to determine the tritium concentrations being recharged. Evaporation of tritiated water from the infiltration basin has been measured, and has been shown not to pose a risk to human health, wildlife, or the environment. Air monitoring stations continue to measure tritium concentrations in air on a regular basis (BNL 1998n).

Once the water has been recharged, it flows southward and will take approximately 19 years to reach the BNL site boundary. Since tritium has a half-life of 12.3 years, natural decay and dilution will have reduced tritium levels to nearly undetectable levels after 19 years. Monitoring wells located at the BNL boundary will provide advance warning should tritium above the drinking water standards come near the boundary of the site (BNL 1998n). In response to other groundwater plumes, DOE had previously installed public water to the residences and businesses downgradient of the site.

The pump-and-recharge remediation is being conducted as an interim remedial action to ensure that tritium above the drinking water standards does not migrate across the BNL boundary. It also gives BNL and DOE time to study alternative remediation technologies and prepare a plan to address the high levels of tritium found immediately south of the HFBR. The long-term remediation of the plume will be determined in the OU III RI/FS (BNL 1998n). This short-term tritium removal action has been incorporated into the BNL cleanup program in accordance with the Interagency Agreement among DOE, EPA, and NYSDEC. The Agreement was signed pursuant to CERCLA. A description of the removal action, the alternatives considered, regulatory interaction, and public participation activities are documented in the *Final Action Memorandum Operable Unit III Tritium Removal Action* (BNL 1997e).

In addition to activities associated with the cleanup of the tritium plume, all fuel has been removed from the reactor and from the spent fuel pool and shipped offsite to DOE's SRS (62 FR 62572). To prevent further leakage, all water in the spent fuel pool was removed in December 1997 and is being temporarily stored in specially constructed tanks in Building 811.

In response to the documented source and movement of the plume, three measures have been or are being taken: 1) removal of spent fuel and water from the HFBR spent fuel pool and installation of a double-walled, impervious stainless steel pool liner (including appurtenant piping and a leak detection system), 2) eliminating other potential sources of leakage by bringing the HFBR into conformance with Suffolk County Sanitary Code, Articles 7 and 12, and 3) groundwater pumping at the leading edge of the plume. With the installation of the spent fuel pool liner system and other measures required to conform with Suffolk County Sanitary Code, Articles 7 and 12, no uncontrolled discharges from the HFBR that might contribute to existing contamination would be expected from implementation of any of the operational alternatives.

The *U.S. Nuclear Regulatory Commission Safety Assessment of the High Flux Beam Reactor at the Brookhaven National Laboratory* (NRC 1999) concluded that "actions taken to characterize and control the groundwater tritium plume were conservative, and this tritium plume does not present a radiological hazard to public health or safety. Monitoring and control of effluents at the HFBR were acceptable. Releases were well below the applicable limits and followed ALARA practices."

1.8.3.3 Current DOE Action

After completion of the initial investigation, the concerns about the tritium plume are addressed in the CERCLA OU III RI/FS. Data collected on groundwater flow indicates that tritium concentrations greater than the drinking water standard will never cross the BNL boundary from the HFBR tritium plume due to natural decay and dilution.

In March, 1999, DOE announced a public comment period on BNL groundwater cleanup documents for OU III: the RI/FS and the *Proposed Plan for Operable Unit III*. These documents address cleanup of groundwater contamination both on and off the BNL site.

The FS addresses remediation of tritium and other contaminants. Cleanup objectives include: meeting drinking water standards in groundwater for tritium and other contaminants; completing cleanup of groundwater in a timely manner, and; preventing or minimizing further migration of contaminants.

The *Proposed Plan for Operable Unit III* identifies proposed remedies for the groundwater contamination. For the tritium plume, since it is expected to decay to levels below the drinking water standard before reaching the site boundary, monitored natural attenuation is proposed. The existing tritium pumping system that was started in 1997 would be placed in standby. This system would be restarted if monitoring of the tritium plume indicates that concentrations of tritium above the drinking water standard could migrate off site. Additional low-flow extraction wells would be installed near the HFBR and operated if tritium concentration levels adjacent to the HFBR increase significantly due to migration of tritium out of the soil beneath the HFBR. Groundwater monitoring would continue.

Proposed remedies may be modified or different removal/remedial actions may be selected based upon public comments. After consideration of public comments, DOE, EPA, and NYSDEC will make a final decision on the OU III cleanup remedies. The decision will be formalized in a ROD, and remediation work will be conducted under the framework of an interagency agreement among the DOE, EPA, and NYSDEC.

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